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Chemical composition of *Acacia colei* and *Acacia tumida* seeds—potential food sources in the semi-arid tropics

Steve R.A. Adewusi[a,*], Olumuyiwa S. Falade[a], Chris Harwood[b]

[a]*Department of Chemistry, Obafemi Awolowo University, Ile-Ife, Nigeria*
[b]*Australian Tree Seed Centre, CSIRO Division of Forestry, PO Box 4800, Q.V.T., Canberra, ACT 2600, Australia*

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Abstract

The seeds of *Acacia colei* (Maslin and Thomson) and *A. tumida* (F. Muell ex Benth.) are traditional foods of Australian Aboriginal people. Chemical analysis was carried out on seeds of *A. colei* trees growing in Maradi district, Niger Republic and *A. tumida* from a natural stand near Kunanurra in north western Australia. Crude protein (N × 6.25) ranged from 23.4% for whole *A. colei* seed to 30.6% for a water-processed *A. colei* sample and 20.4% for *A. tumida*. True proteins were 19.9, 25 and 18.5% and ether extracts 10.9, 18.9 and 8.1% for these samples, respectively. Amino acid analysis indicated that tryptophan was the first limiting amino acid in all the acacia samples. Dietary fibre, calculated on defatted and ethanol extracted samples, was highest in whole *A. colei* with the seed coat (47.9%) and lowest in the processed *A. colei* (31.9%). Total soluble sugar was highest in *A. tumida* (14.6%). Both *A. colei* and *A. tumida* seeds contained high levels of linoleic acid. Fat soluble vitamins (carotenoids, ergocalciferol and α-tocopherol) were generally inadequate while the water-soluble vitamins (B group) were in sufficient to large quantities. Processing *A. colei* with water reduced thiamine, niacin, riboflavin and pantothenic acid contents by 12, 31, 42 and 74%, respectively. Potassium was the predominant mineral in all the acacia samples. Iron, magnesium, calcium and zinc were in high concentrations; the availability of iron was low but that of other elements was adequate.

Keywords: Proximate; Amino and fatty acid composition; Vitamins; Minerals

1. Introduction

Hunger, famine, malnutrition and its attendant diseases are major public health issues in the semi-arid Sahel, the sub-Saharan West African region, stretching from Senegal in the west to Chad in the east (Advisory Committee on the Sahel, 1984). Millet and sorghum are the main food sources and account for the major part of the area under cultivation. Drought and/or pest attack lead to serious and repeated failures of these crops.

Australia is the world's driest continent with about 50% of the land area receiving less than 300 mm of annual rainfall, and possessing generally infertile soils (Turnbull, 1986), and it has a diverse range of plants suited to the arid and semi-arid regions. These include fast-growing phyllodenous *Acacia* species, a number of which have been widely tested in Sahelian Africa and which have displayed excellent survival, growth and seed production in the 400–700 mm mean annual rainfall zone (Cossalter, 1987; Rinaudo et al., 1995; Souvannavong & de Framond, 1992).

About 50 of Australia's dry zone *Acacia* species are known to have been significant seasonal components of traditional Aboriginal diets (Devitt, 1992) and their potential as a food source, for the famine-prone Sahelian region, may be significant (Harwood, 1994). The present set of studies was therefore planned to investigate the chemical and nutritional aspects of acacia seeds, in particular *A. colei* (Maslin & Thomson, 1992) which grows well and produces abundant seed around Maradi, Niger Republic, as a prelude to their incorporation in traditional diets or for use as a famine food.

2. Materials and methods

A. colei seeds were collected from trees growing around Maradi, Niger Republic by Mr Tony Rinaudo, (SIM Project Director, Maradi) and supplied as a 100 kg

* Corresponding author.
E-mail address: sadewusi@oauife.edu.ng (S.R.A. Adewusi).

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batch. Five kilograms of *A. tumida* F. Muell. ex Benth. seeds from CSIRO seedlot No. 18545, collected near Kunanurra, Western Australia in 1992, were supplied by the Australian Tree Seed Centre. The two seedlots were cleaned by removing stones, fragments of wood and resinous matter by hand and milled in a local mill.

2.1. Processing methods

1. The milled *A. colei* seed served as the first sample and is hereinafter referred to as *A. colei* (whole seed).
2. Water was added to the milled seed in a small plastic container and the mixture swirled and decanted. This procedure was repeated many times until the bulk of the cotyledon was separated from the seed coat. The cotyledon flour thus separated was then air-dried, milled again and kept at room temperature (water-processed *A. colei* sample).
3. Milled *A. colei* was sieved using a local sieve to remove the coarser fragments of the seed coat. The success of this process largely depends on how finely the seeds have been milled. The product is referred to as sieved *A. colei*.
4. *A. tumida* seeds were also milled using the local mill. During this process part of the seed coat separated from the flour, probably due to lightness in weight (*A. tumida*).

All samples were milled as one batch, mixed thoroughly and sub-samples taken from different parts of each sample.

2.2. Analytical procedures

The moisture contents of triplicate seed samples were determined by the AOAC (1984) procedure. Nitrogen was determined, on a dry weight basis, by the micro-Kjeldahl method (AOAC, 1984) and crude protein estimated by multiplying the nitrogen content by 6.25. True protein was determined by both the colorimetric and precipitation methods.

2.2.1. Colorimetric method

Protein was extracted from 1.0 g samples as described by Murray and McGee (1986). The protein content of 0.1 mL of the extract was precipitated by 80% ethanol and the precipitate redissolved in 4 mL 0.25 M NaOH. Protein was then determined by the biuret method, as described by Gornall, Bardwill, and David, (1949) using 2 mg/mL bovine serum albumin as a standard.

2.2.2. Precipitation method

Ten grams of seed flour was mixed with 100 mL water and the pH adjusted to 8 or 10 by adding NaOH solution. The mixture was heated at 62 °C for 1 h, cooled, the pH adjusted again to 4 to precipitate the protein, and left overnight to settle. The precipitate was filtered, dried, weighed and sub-samples used for nitrogen determination by the micro-Kjeldahl method.

2.2.3. Amino acids

Amino acid composition was determined on single assay basis at the State Chemistry Laboratory, East Melbourne, Victoria, Australia on single samples using a Millipore Waters HPLC but otherwise following the methods of Fox, Rayner, and Wu (1991). Tryptophan was analysed using the methods of Delhaye and Landry (1986). The per cent coefficient of variation (CV) of the amino acid content of a standard casein sample run alongside the samples were aspartic acid—5.2, threonine—4.3, serine—5.2, glutamic acid—4.3, proline—7.1, glycine—11.3, alanine—18.7, valine—6.9, methionine—4.0, isoleucine—6.0, leucine—3.0, tyrosine—5.4, phenylalanine—4.5, lysine—4.5, histidine—5.8, ammonia—10.1, and arginine—10.6.

2.2.4. Ether extract

Ether extract was determined on triplicate samples with petroleum spirit in a Soxhlet extractor. Dietary fibre was determined by the procedure of Lee, Prosky, and de Vries, (1992). Soluble sugar was extracted three times from 2-g samples with 80% ethanol, filtered and the residue washed with the same solvent to give a total volume of 50 mL. Total sugar was then estimated by the modified anthrone method according to Cerning-Beroard (1975) using glucose as a standard.

2.2.5. Determination of total mineral content

One-gram sample was twice digested to dryness with 20 mL *aqua regia* (1 part HNO_3 + 3 parts HCl) and twice with $HClO_4$ and the residue made up to 20 mL with 1 M HCl. Minerals in the digestate above were determined by inductively coupled plasma–optical emission spectrometry (ICP–OES).

2.2.6. Determination of available minerals using in vitro technique

The milled seeds were heated at 70 °C for 30 min (Harwood, 1994) to simulate cooking and then subjected to the in vitro digestibility procedure. The method of Miller, Schricker, Rasmussen, and van Campen, (1981) was used, except that radio-labelled iron was not included in the assay. The mineral content of the dialysis tubes was estimated by ICP–OES after the protein content had been precipitated by 10% TCA. Analysis was carried out in duplicate. The percent CV for standards run at the beginning and the end of each assay period were B—1.9, Zn—2.4, Pb—1.8, Cd—2.4, Co—1.9, Ni—1.3, Cr—0.7, Cu—1.1 for liquid samples while those of solid samples were Mn—0.9, Fe—1.1, Mg—0.55, Al—1.6, Ca—1.2, Na—3.7 and K—1.2.

2.2.7. Fatty acids

Fatty acid composition was determined by the Human Nutrition Unit, Biochemistry Department, Sydney University, Australia. Two-gram samples were extracted with 30 ml chloroform–methanol (2:1) mixture and 6 ml saline solution were added with vigorous shaking in a separatory funnel. The other preparatory procedures have been outlined by Brand and Cherikoff (1985) and Brown, Cherikoff, and Roberts, (1987). The extracted the fatty acids were analysed using gas chromatography and flame ionization detection.

2.2.8. Vitamin contents

Vitamin content of whole and processed *A. colei* and *A. tumida* was determined on single sample basis by the Australian Government Analytical Laboratories, South Australia Regional Laboratory, Seaton, South Australia. Thiamin and riboflavin were determined in samples after acid and enzymatic digestion by the HPLC, AOAC 43.024, 43.026 (1980) method. CVs from multiple sample analyses of standard foods were thiamin 2–10% and riboflavin 4–6%. The CV of niacin determined colorimetrically after alkaline hydrolysis using AOAC 43.045 (1980) method was 10%.

Samples were hydrolysed, extracted and alpha, beta carotenes, cryptoxanthin and ergocalciferol (D_2) determined by HPLC method with a CV of 10%. Alpha tocopherol similarly determined had a CV of 4%. Pantothenic acid was extracted with 0.2 M acetate buffer and determined microbiologically (CV—15%).

3. Results and discussion

3.1. Chemical composition

The results presented in Table 1 show that the moisture contents of the samples were generally low (less than 8%). This is comparable with 7.2 and 7.4% recorded for two provenances of *A. tumida* (CSIRO seedlot nos. 15745 & 17046, respectively) and 6.6% for *A. colei* (14561). The crude protein content was very high with the water-processed *A. colei* containing 30.6% and *A. tumida* 20.4%. Brand-Miller and Maggiore (1992) estimated the crude protein contents of *A. cowleana, A. holosericea* (a species within which *A. colei* was formerly included (see Maslin & Thomson, 1992) and *A. tumida* to be 23.8, 24.6 and 17.6%, respectively. The difference between their results and those now presented could be attributed to processing, which removed a substantial part of the seed coat, which acted as a nutrient diluent in the samples analysed by Brand-Miller and Maggiore (1992). The 23.4% crude protein content recorded for the whole seed sample of *A. colei* from Maradi falls within the range above and that reported by Vijayakumari, Siddhuraju, and Janardhanan, (1994) for *A. leucophloea*.

Murray and McGee (1986) have observed that acacia seeds contain a substantial level of non-protein nitrogen and reported extractable proteins of *A. cowleana* and *A. holosericea* determined by the biuret method to be 10.4 and 9.3%, respectively. Using the method of Murray and McGee (1986), the true (extractable) protein content of *A. colei* with the seed coat was found to be 19.9%; that for the water-processed sample was 25% while *A. tumida* was 18.5%. Again these values are higher than those reported by Murray and McGee (1986).

The amino acid profiles of the three *A. colei* samples and *A. tumida* are presented in Table 2. The potential food value of these seeds (as a source of amino acids) can be evaluated by comparison with the FAO reference pattern (FAO/WHO/UNU, 1985). Using the true digestibility values obtained in our rat bioassay (Adewusi et al. in preparation), the protein digestibility-corrected amino acid score (FAO/WHO, 1991) for whole *A. colei* seed flour was highest for histidine (99%), high for valine (82%) and lowest for tryptophan (50%),

Table 1
Chemical composition of acacia seeds (% dry weight)

	Mean and standard deviation of 3–5 replicates			
	A. colei	*A. colei* water-processed	*A. colei* sieved	*A. tumida*
Moisture	8.0±0.4	6.3±0.4	6.5±0.8	7.9±0.6
Crude protein	23.4±1.2	30.6±1.1	21.4±0.4	34.1±1.2
True protein: colorimetric method	19.9±2.7	25.0±2.7	–	18.5±2.6
True protein: ppt at				
pH 8	5.2±0.3	11.5±0.2	–	7.7±0.3
pH 10	14.7±0.6	9.9±0.6	–	11.8±0.3
Ether extract	10.9±0.2	18.9±0.3	12.1±0.6	8.1±0.3
TDF[a]	47.9±0.7	31.9±0.1	33.0±0.7	41.2±0.8
TDF[b]	39.9±0.3	15.9±0.1	29.1±1.8	20.3±0.4
Total sugar[c]	12.4±1.7	9.0±1.7	13.7±2.0	14.6±1.5

– = Not analysed

[a] Total dietary fibre (TDF) based on defatted and 80% ethanol-extracted samples;

[b] TDF as is

[c] Total sugar–Total 80% ethanol-soluble sugar.

Table 2
Amino acid content and protein digestibility-corrected amino acid score[a] (in parentheses)[b] of some acacia seeds

Amino acids	Ref[c]	*A. colei* whole	*A. colei* water-processed	*A. colei* sieved	*A. tumida*
Asp		19.0 (61)	23.1	22.5	21.9
Thr	34	8.3	11.8 (79)	9.1 (63)[d]	8.0 (80)
Ser		12.5	17.3	13.6	12.3
Glu		30.5	40.1	33.4	30.5
Pro		8.9	13.3	10.2	9.9
Gly		11.8	13.2	11.6	12.1
Ala		9.3	12.7	10.3	9.0
Val	35	11.6	14.9 (97)	12.7 (85)	13.4 (130)
Met		3.2	4.3	3.5	2.6
Ile	28	8.8 (78)	11.9 (97)	9.7 (81)	8.4 (102)
Leu	66	17.2 (65)	23.3 (81)	18.6 (66)	16.1 (83)
Tyr		8.4	11.0	8.5	7.9
Phe		9.9	12.7	10.0	8.9
Lys	58	14.3 (61)	16.0 (63)	16.5 (67)	15.2 (89)
His	19	7.6 (99)	7.9 (95)	8.0 (99)	7.1 (127)
NH_3		4.4	5.8	4.5	4.3
Arg		15.1	19.1	17.4	15.2
Cys & Cy		2.9	3.3	3.1	2.8
Trp	11	2.2 (50)	2.7 (56)	2.5 (53)	1.9 (59)
Met + Cys	25	6.1 (61)	7.6 (70)	6.6 (62)	5.4 (73)
Phe + Tyr	63	18.3 (72)	23.7 (86)	18.5 (69)	16.8 (91)
Nitrogen		37.4	48.9	39.5	32.0
E.A.A. as% of total including His[e]		45.6	45.3	45.3	44.5
% True digestibility		58	70	58	68

[a] Protein digestibility-corrected amino acid score was calculated using the true digestibility of acacia seeds in a 28-day rat bioassay (to be reported elsewhere) as outlined by FAO/WHO, 1991.
[b] All values in parentheses are calculated by first converting the amino acid values to g/kg protein and expressed as% of reference value.
[c] Reference—the amino acid requirement for pre-school children 2–5 years old) as expressed in g/100 g protein (FAO/WHO, 1985).
[d] Based on a 58.2% true digestibility for the whole acacia seed, but recent bioassay gave values for true digestibility as low as 19% (reported elsewhere).
[e] E.A.A.—essential amino acids.

making the latter the first limiting amino acid with the sulfur amino acids and threonine jointly second (61%). The protein digestibility-corrected amino acid score of sieved *A. colei* was similar to that of the whole seed flour, probably because a 58% true digestibility was also assumed for this sample. In both cases, the order of amino acid limitation was tryptophan, methionine + cystine $\geqslant$ threonine, leucine/lysine and all these amino acids have scores below 70%.

Processing *A. colei* seed flour with water to remove part of the seed coat resulted in a sample with higher protein content; tryptophan was still the first limiting amino acid but with lysine and the sulfur amino acids as the second and third limiting, respectively. Processing with water seemed to improve the overall content of the protein's essential amino acid, probably due to the loss of some protein fractions during the procedure. The amino acid profile of *A. tumida* showed that the essential amino acids, such as valine, histidine and isoleucine, are at higher concentrations when compared with the reference pattern (FAO/WHO/UNU, 1985), while the other essential amino acids are adequate (80% and above), with the exception of tryptophan and methionine + cystine, which are the first and second limiting amino acids, respectively.

The amino acid profile and hence protein content of *A. tumida* (Table 2) seems more balanced and therefore better than those of *A. colei* (whole and processed) and would partially account for the better performance of rats fed *A. tumida* in comparison to those fed *A. colei* seed flour (Adewusi et al. in preparation). Vijayakumari et al. (1994) reported high amino acid scores for purified total seed proteins of *A. leucophloea* and that the sulfur amino acids (methionine and cysteine) were the first limiting amino acids, though tryptophan was reported as undetectable. In the present study, tryptophan was detected, but was present at a low level so as to become the first limiting amino acid in all the samples investigated. It should, however, be noted that the values presented in parentheses in Table 2 are protein digestibility corrected, whereas the "conventional" amino acid score like those calculated by Vijayakumari et al. (1994), would exceed 100% of the recommended value for all the essential amino acids except tryptophan in all the *Acacia* samples investigated. Sastry and Murray (1986) reported that the tryptophan content (1.6–2.7% by weight) of Australian acacia seed proteins is usually greater than that of the cultivated legumes. The highest tryptophan content in our samples was 0.9% of the

total protein content. The discrepancy between the present result and those of Sastry and Murray (1986) could be due to species or provenance differences or the lower level of protein extraction obtained by the earlier workers.

Total dietary fibre contents calculated on defatted and 80% ethanol-extracted samples were 47.9, 31.9, 33.0 and 41.2% for *A. colei* whole seed, water-processed, and sieved samples and *A. tumida*, respectively (Table 1). This is in general agreement with the values of 44.9, 34.5 and 56% reported for whole *A. cowleana, A. holosericea* and*A. tumida* samples, respectively (Brand-Miller & Maggiore, 1992). The partial removal of the seed coat in *A. colei*, either by processing with water, or sieving, reduced the dietary fibre by about one third while the lower value now reported for the dietary fibre of *A. tumida* could also be due to the partial removal of the seed coat during milling and sieving. When the present total dietary fibre values are expressed on the basis of the whole seed sample, including its lipid and sugar contents (as is), whole *A. colei* seeds still have the highest dietary fibre content of 39.9%.

Sugar extracted with 80% ethanol, which includes both reducing and non-reducing sugars, as well as oligosaccharides, was highest in *A. tumida* (14.6%) and lowest in the processed *A. colei* (9.0%) with glucose as the reference standard. Ether extract was highest (18.9%), as expected in water-processed *A. colei* (removal of the dilution factor), 12.2% in the sieved sample, 10.9% in the whole seed sample and 8.1% in *A. tumida*. Brand-Miller and Maggiore (1992) reported levels of 11.0, 7.7 and 6.4% for the fat contents of *A. cowleana, A. holosericea* and*A. tumida* (CSIRO seedlot 17046) respectively, while Vijayakumari et al. (1994) reported a crude lipid content of 5.1% for *A. leucophloea*.

The fatty acid compositions of the ether extract of *A. colei* and*A. tumida* presented in Table 3 indicate that linoleic acid, was the predominant fatty acid constituting 55.9% of the fatty acid in the whole seed flour of *A. colei*, 50.1% in both sieved *A. colei* and *A. tumida* seed flours and 31.7% in the water-processed *A. colei* seed sample. The linoleic acid values of whole seed flour of *A. colei* and *A. tumida* were comparable to that reported (51.1%) by Vijayakumari et al. (1994) for *A. leucophloea* and other commonly consumed legumes, such as soybean, chick pea and horse grain (Salunkhe, Sathe, & Reddy, 1982). The unsaturated fatty acids constitute the bulk of the fatty acids, as in the case of certain edible legumes, such as *Phaseolus vulgaris* and*Vigna unguiculata* (Omogbai, 1990) and in agreement with the finding of Vijayakumari et al. (1994). It has been suggested that the appropriate proportions of the total saturated, total monounsaturated and total polyunsaturated fatty acids (S:M:P) are 1:1:1 (FAO, 1980). The S:M:P ratio for whole *A. colei* seed was 1.1:1:2.9 and was 1.2:1:2.2 for *A. tumida* seed lipids. While the S:M ratio is appropriate in these two samples, the M:P ratios are 190 and 120% higher, respectively. Current opinion favours an adequate intake of n-3 fatty acids, especially the C20:5 and C22:6 which are conspicuously absent in these seeds. Processing *A. colei* seed flour in water to remove part of the seed coat resulted in a modified fatty acid profile with a 43% decrease in the linoleic acid content and 28, 89, 19, 93 and 76% increases in palmitic, stearic, oleic, arachidonic and behenic acids, respectively. The S:M:P ratio was also modified to 1.4:1:1.4, which is a better proportion than the fatty acid profile of the *A. tumida* and the unprocessed *A. colei* seeds. The combination of acacia seeds, which have oils rich in polyunsaturated fatty acids, with oils rich in monounsaturated fatty acids, such as palm-oil (Ekpa, Fubara, & Morah, 1994) and *Moringa oleifera* seed oil (Adewusi, unpublished data), would give a ratio close to the ideal.

3.2. Vitamins

The data on vitamins for whole and water-processed *A. colei* seed flours are presented in Table 4. The vitamin A precursor, β-carotene, and to some extent α-carotene, were both very low in the two flours investigated. Starchy carbohydrate sources contain between 30 and

Table 3
Fatty acid composition (percentage of total) of *Acacia colei* and *A. tumida* seed flour lipids

	A. colei whole	*A. colei* water-processed	*A. colei* sieved	*A. tumida*
Palmitic acid C16:0	11.4	14.6	14.4	9.4
Palmitoleic acid C16:1	0.30	0.31	0.8	0.0
Stearic acid C18:0	3.7	7.0	3.5	6.9
Oleic acid C18:1 (n-9)	18.0	21.5	23.5	22.1
Vaccenic acid C18:1 (n-7)	1.1	1.2	1.4	0.7
Linoleic acid C18:2	55.9	31.7	49.1	50.1
Arachidonic acid C20:0	1.4	2.7	1.2	4.1
Behenic acid C22:0	4.1	7.2	3.5	4.9
Lignoceric acid C24:0	1.2	1.5	1.0	1.8
Saturated: unsaturated ratio	1 : 3.5	1 : 1.7	1 : 3.2	1 : 2.7
Saturated:Monounsaturated: Polyunsaturated ratio	1.1:1:2.9	1.4:1:1.4		1.2:1:2.2

Table 4
The vitamin content of whole and water-processed *Acacia colei* seed flour

	Whole seed	Water-processed
Moisture% m/m	10.0	7.6
Alpha carotene μg/100 g	<5	<5
Beta-carotene μg/100 g	<5	<5
Cryptoxanthin μg/100 g	5.6	<5
Thiamin (B_1) mg/100 g	0.34	0.30
Riboflavin (B_2) mg/100 g	0.36	0.21
Niacin mg/100 g	4.2	2.9
Pantothenic acid μg/100 g	1500	390
Ergocalciferol (D_2)	[a]	<5
α-tocopherol (E) mg/100g	0.30	0.74

[a] Unable to identify due to a large number of interferences.

4800 μg β-carotene/100 g fresh weight (Bradbury & Holloway, 1988) which is at least 6–1000 times the content now reported for the two samples. Cryptoxanthin is a non-vitamin A precursor but its presence in acacia seeds is a valuable attribute, since carotenoids in this category are now known to be involved in immune-enhancement, treatment and prevention of cancer and reduction of morbidity and mortality in children of the third world (Adewusi & Bradbury, 1993). FAO/WHO (1988) recommended a daily intake of 400 μg RE (β-carotene μg/6 RE) for infants and children and 600–800 μg RE for adult men and women. Zhao (1988) reported absorption rates ranging from 20 to 45% for various leafy vegetables, roots and tubers, while low fat intake, such as in tropical countries, reduces carotenoid absorption by about one-third. *Acacia* seeds cannot therefore be expected to supply the dietary need of vitamin A. It would therefore be advisable to complement *Acacia*-based diets with green and yellow leafy vegetables, in food preparations such as massolali, part of the traditional diet of the people of Maradi district.

Thiamine (vitamin B_1) is relatively high in both whole and processed *A. colei* seed flours, such that 300–400 g of the flour would supply the Australian recommended dietary intake (RDI) of 1.1 mg/day for men of 19–64 years old and 0.8 mg for women of the 19–54 years' age group [National Health and Medical Research Council (NHMRC) 1991]. The thiamine content of whole *A. colei* seed flour is higher than those reported for the conventional starchy carbohydrate roots and tubers—0.071–0.296 mg/100 g dry weight (Bradbury & Holloway, 1988), comparable with the thiamine content of sorghum (0.29 mg), white and yellow maize (0.30–0.33 mg) but lower than in the rice bran—2.15 mg/100 g (FAO, 1968). Water-processing of *A. colei* seed flour only marginally reduced the thiamine content of the product by 12%. Riboflavin (vitamin B_2), active as part of flavine mononucleotide or flavine adenine dinucleotide prosthetic groups, is involved in the respiratory chain and oxidative phosphorylation. It is relatively unstable when tissue protein is depleted by physiological stress, dietary deficiency or disease—states which may occur during drought in the Sahel region of Africa. This vitamin is higher in the acacia samples than in the conventional root crops—0.06–0.23 mg /100 g dry weight (Bradbury & Holloway, 1988) and the conventional starchy cereals, such as maize, sorghum, millet and barley (FAO, 1968). Riboflavin was substantially affected by processing *A. colei* seed with water, the concentration being reduced by about 42% during this procedure. The RDI in Australia for riboflavin—1.7 mg/day for men of 19–64 years of age and 1.2 mg/day for women of 19–54 years of age would be supplied by about 500 g of the whole seed flour and 700 g of the processed sample, respectively.

Niacin is incorporated into the nicotinamide adenine dinucleotides to form the prosthetic group of some enzymes also involved in the electron transfer reactions of the respiratory chain and in oxidative phosphorylation. The RDI of 18 mg niacin equivalents/day for male and 15 mg/day for women of 35–50 years of age, can be supplied by less than 500 g of whole *A. colei* seed flour. Though exceedingly stable, processing with water reduced the niacin content of *A. colei* seed flour by 31%, presumably through leaching by water and/or removal of niacin bound to the seed coat. About 800 g of the processed *A. colei* seed flour, which could be consumed within a day, would provide the niacin requirement that would at least prevent pellagra within the community. Though niacin requirement cannot be dissociated from tryptophan intake (60 mg tryptophan forms 1 mg niacin), in *A. colei* seed flour, tryptophan is the first limiting amino acid (Table 2), which means that this amino acid may not be available for the sparing role of niacin.

Pantothenic acid is abundant in the whole seed but the level is substantially decreased (74%) by processing with water to remove the seed coat. The adult daily requirement, estimated as 5–10 mg, would be supplied by 400 g of the whole seed flour, while the processed sample may not be able to meet the recommended daily intake.

Ergocalciferol, (D_2) is one of the most active vitamins but the level in acacia seed flour is rather low and may not be able to meet the recommended 10 μg/day requirement. Alpha-tocopherol (E) is abundant in lipids and oils (Desai, Bhagavan, Salkeld, & de Oliveria, 1988). The vitamin E content of acacia seed flour is low when compared to that of the different varieties of corn—4.2–9.9 mg/100 g corn (Contreras-Guzman & Strong, 1982; Contreras-Guzman, Strong, & da Silva, 1982). The recommended daily intake of 8–10 mg can only be supplied by more than 1 kg of the processed seed flour. A ratio of 0.4 mg of α-tocopherol to 1 g polyunsaturated fatty acids (PUFA) is considered adequate in the American diet (Bieri & Evarts, 1973). The whole seed and processed flours contain 10.9 and 18.9% crude lipid, out of which 56 and 32%, respectively, is

PUFA. The alpha tocopherol to PUFA ratios of 0.05 mg/g for the whole seed flour and 0.1 mg/g for the processed sample therefore seem inadequate.

3.3. Minerals

Mineral analysis (Table 5) showed that potassium is the predominant element in all the acacia samples in agreement with the finding of Brand-Miller and Maggiore (1992) and Vijayakumari et al. (1994) who reported analyses of about 70 different acacia seed samples. Severe hyperkalaemia—plasma [K] > 7.5 mmol/L—is a medical emergency because of its potential effect on the heart (Walmsley, Watkinson, & Koay, 1992). The bioavailability of potassium in acacia therefore becomes an important parameter when investigating the potential nutritional consequences of acacia diets. Between 32 and 34% of the potassium in acacia seed samples is bioavailable as estimated by the in vitro method and may not cause an overload provided that the function of the kidney remains unimpaired. The gross histology and weight of the kidney of rats fed acacia based diets have not revealed any major distortion (Adewusi et al. in preparation-a, in preparation-b) and the electrolyte balance is therefore expected to be maintained.

The iron content of *Acacia* samples in the present study varied from 18 mg/100 g in the processed *A. colei* to 54.4 mg/100 g in *A. tumida* seed flour. A value of 22 mg/100 g seed was reported for *A. leucophloea* while Brand-Miller and Maggiore (1992) reported a range of 3.2–81.4 mg/100 g for different acacia seeds. A range of 5–12 mg iron/100 g sample was recorded by Adewusi and Falade (1996) for legume seeds, showing that acacia seeds seem to contain an appreciable amount of iron. The Australian recommended dietary allowance (RDA) for iron is 7 mg/day for men but women need about twice this amount (12–16 mg/day) during pregnancy (Lehrfeld & Wu, 1991; NHMRC, 1991). The RDA

Table 5
Total mineral content and percentage availability in some acacia seed samples (mg/100g)

Element	*A. colei* whole	*A. colei* water-processed	*A. tumida*	*A. leucophloea*[a]	*Acacia* species[b]
Na	A 7	–	–	32±0.1	3–131
	B–	–	–	–	
K	A 934	443	914	1020±1.2	78–1795
	B 34.1	36.0	31.7	–	–
Fe	A 31	18	54.4	22±0.3	32–81.4
	B 2.0	2.5	7.9	–	–
Mg	A 290	153	261	261±0.6	118–280
	B 15.1	16.3	16.4	–	–
Zn	A 3	5	2.25	6±0.1	1.2–7.4
	B 54.3	16.4	30.6	–	–
Ca	A 274	206	168.4	314±1.0	54–555
	B 7.0	7.4	10.9	–	–
Mn	A 8.0	4.0	314	4±0.1	–
	B 5.8	6.4	7.2	–	–
Cu	A 0.6	0.9	0.7	2±0.1	0.0–4.2
	B 66.7	53.3	35.8	–	–
Al	A 6.0	11.0	–	–	–
	B 3.6	2.0	–	–	–
Pb	A 0.1	0.2	0.0	–	–
	B 125	21.6	0.0	–	–
Cd	A nd	nd	nd	–	–
	B nd	nd	nd	–	–
Co	A nd	nd	nd	–	–
	B nd	nd	nd	–	–

A, Total mineral content in mg /100 g. B, Percentage availability.
[a] Values from Vijayakumari et al. (1994)
[b] Values from Brand-Miller and Maggiore (1992), range of 26 species. nd, Not detected. –not analysed

would be supplied by 100 g of the processed *A. colei* or 30 g of *A. tumida* seeds but unfortunately, the iron content of acacia seeds is only 1–7.9% available, as determined by the in vitro digestion method as against the 15–20% availability assumed by NHMRC (1991) in the presence of meat protein and vitamin C in Australian diets and the 10% availability assumed by the UK RDA. An adult would only need to ingest 267 g of processed *A. colei* or 50 g of *A. tumida* to supply the RDA requirement, even with this in vitro bioavailability. The bioavailability of iron, especially in *A. colei* is low when compared to 9–28% availability in some legume seeds (Adewusi & Falade, 1996). The low availability may not be unconnected with the low protein digestion and the presence of a high level of dietary fibre (Table 1).

Symptoms of magnesium deficiency include haematological neutropenia and leucocytosis (Battiflora, McCready, & Hahneman, 1968; Hungerford & Karson, 1960) which were observed in experimental rats fed *A. colei* based rations (Adewusi et al. in preparation-a, in preparation-b). This calls to question whether the observed symptoms were indeed due to magnesium deficiency. The magnesium content of *Acacia* samples investigated in this study is comparable with the 140–237 mg/100 g sample reported for various legumes by Adewusi and Falade (1996) and 118–280 mg/100 g seed reported by Brand-Miller and Maggiore (1992) for various acacia species. The availability of magnesium is comparable to its availability in cooked legume seeds if we assume that 50% of the ionised form (in the legume) is bioavailable. The neutropenia and leucocytosis observed in acacia-fed rats could not therefore result from magnesium deficiency. Indeed, about 1 kg of processed *A. colei* seed flour alone would supply the RDA of 320 mg /day for men aged 19–64 years and for women 19–54 years of age (NHMRC, 1991).

Total manganese content of acacia samples is higher in this study than in the reported 4.0 mg/100g in *A. leucophloea* (Vijayakumari et al., 1994) except in the processed *A. colei* seed flour where most elements are reduced, probably as a result of leaching by water and/or loss in the protein and seed coat (fibre) fractions.

Total content of zinc was within the range reported by earlier workers while its bioavailability was very high such that 1.2 kg of the processed *A. colei* seed flour could supply the 12 mg/day RDA for men aged 19–64 years and women 19–54 years of age (NHMRC, 1991).

Heavy metals—Pb, Cd and Co—only exist in traces or are not detectable and would not constitute any toxicity problem.

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